d.) Remarks

Claim 1-23 are pending in the application. Claims 1 and 17 are amended. Claims 8-16 are canceled. Applicant is grateful to the examiner for a helpful interview on October 29, 2003.

Claims 1-7 and 17-23 were rejected under 35 USC 103(a) over U.S Patent No. 4,463,243 ("Church") in view of U.S. Patent No. 4,800,131 to Marshall et al. ("Marshall"). Applicant respectfully asserts that amended independent Claim 1 specifically points out that the wire of the present invention is utilized in a straight polarity welding configuration (DCEN). As follows from various excerpts of the publications enclosed with this response, they all teach away from using the DCEN configuration in gas metal arc welding because of arc instability and spatter problems (Jefferson's *Welding Encyclopedia*, 18th Edition, Cary's *Modern Welding Technology*, 2nd Edition, *The Procedure Handbook of Arc Welding*, AWS' *Welding Handbook*, 7th Edition). No teachings of Church in combination with Marshall hint or suggest that the wire of amended Claim 1 can be successfully used in a DCEN welding configuration. Contrary to the accepted view in the art, the composition of the wire as recited in amended Claim 1 has indeed been successfully used in the DCEN gas-metal arc welding configuration and, therefore, cannot be anticipated by Church in combination with Marshall. Allowance of amended independent Claim 1 and its dependent Claims 2-7 is respectfully requested.

Similarly, in addition to the already recited step of coupling the welding apparatus to a power source in <u>the straight polarity configuration</u> in the body of independent Claim 17, amended claims 17 recites that the claimed welding process takes place in the direct current (DCEN) configuration, contrary to the teaching of the existing state of the art. No teachings of Church in combination with Marshall hint or suggest that the wire of amended Claim 17 can be successfully used in a DCEN welding configuration process. Contrary to the accepted view in the art, the composition of the wire as recited in amended Claim 17 has indeed been successfully used in the DCEN gas-metal arc welding

configuration process and, therefore, cannot be anticipated by Church in combination with Marshall. Allowance of amended independent Claim 17 and its dependent Claims 18-23 is respectfully requested.

Examiner is kindly invited to telephone the undersigned attorney to discuss any matters expediting allowance of the pending Claims.

Respectfully submitted,

Maria Eliseeva

Maria Eliseeva, Reg. No. 43,328
Customer No: 29127
Houston Eliseeva LLP
4 Militia Drive, Suite 4
Lexington, MA 02421
Phone: 781-863-9991
Fax: 781-863-9931
e-mail:maria@patentbar.com

Dated: November 10, 2003

Jefferson's

WELDING ENCYCLOPEDIA

Eighteenth Edition

Edited by
ROBERT L. O'BRIEN

American Welding Society
550 N.W. LeJeune Road, Miami, FL 33126 USA

Printed in the United States of America.

Library of Congress Catalog Card Number: 97-070432
International Standard Book Number: 0-87171-506-6

Photocopy Rights

At the low-current levels for each electrode size, the ve is nearly linear. However, at higher welding curts, particularly with small diameter electrodes, the ves become nonlinear, progressively increasing at a her rate as welding amperage increases. This is ibuted to resistance heating of the electrode exten- beyond the contact tube.

Vith all other variables held constant, an increase in ding current (electrode feed speed) will result in following:

1) An increase in the depth and width of the weld etration

2) An increase in the deposition rate

3) An increase in the size of the weld bead

ulsed spray welding is a variation of the GMAW cess in which the current is pulsed to obtain the antages of the spray mode of metal transfer at aver- currents equal to or less than the globular-to-spray sition current.

ince arc force and deposition rate are exponeny dependent on current, operation above the transi- current often makes the arc forces uncontrollable e vertical and overhead positions. By reducing the age current with pulsing, the arc force and deposi- rates can both be reduced, allowing welds to be le in all positions and in thin sections.

Vith solid wires, another advantage of pulsed er welding is that larger diameter wires, i.e., mm (1/16 in.) can be used. Although deposition s are generally no greater than those with smaller eter wires, the advantage is in the lower cost unit of metal deposited. There is also an increase leposition efficiency because of reduced spatter

/ith metal cored wires, pulsed power produces an hat is less sensitive to changes in electrode exten- (stickout) and voltage compared to solid wires. s, the process is more tolerant of operator guidance uations. Pulsed power also minimizes spatter n an operation already low in spatter generation.

Polarity

he term *polarity* is used to describe the electrical ection of the welding gun with relation to the inals of a direct current power source. When the power lead is connected to the positive terminal, polarity is designated as direct current electrode tive (DCEP), arbitrarily called *reverse polarity*. n the gun is connected to the negative terminal, polarity is designated as direct current electrode tive (DCEN), originally called *straight polarity*.

The vast majority of GMAW applications use direct current electrode positive (DCEP). This condition yields a stable arc, smooth metal transfer, relatively low spatter, good weld bead characteristics, and greatest depth of penetration for a wide range of welding currents.

Direct current electrode negative (DCEN) is seldom used because axial spray transfer is not possible without modifications that have had little commercial acceptance. DCEN has a distinct advantage of high melting rates that cannot be exploited because the transfer is globular. With steels, the transfer can be improved by adding a minimum of 5% oxygen to the argon shield (requiring special alloys to compensate for oxidation losses) or by treating the wire to make it thermionic (adding to the cost of the filler metal). In both cases, the deposition rates drop, eliminating the only real advantage of changing polarity. However, because of the high deposition rate and reduced penetration, DCEN has found some use in surfacing applications.

Attempts to use alternating current with the GMAW process have generally been unsuccessful. The cyclic wave form creates arc instability due to the tendency of the arc to extinguish as the current passes through the zero point. Although special wire surface treatments have been developed to overcome this problem, the expense of applying them has made the technique uneconomical.

Arc Voltage (Arc Length)

Arc voltage and *arc length* are terms that are often used interchangeably. It should be pointed out, however, that they are different even though they are related. With GMAW, arc length is a critical variable that must be carefully controlled. For example, in the spray-arc mode with argon shielding, an arc that is too short experiences momentary short circuits. They cause pressure fluctuations which pump air into the arc stream, producing porosity or embrittlement due to absorbed nitrogen. Should the arc be too long, it tends to wander, affecting both the penetration and surface bead profiles. A long arc can also disrupt the gas shield.

With all variables held constant, arc voltage is directly related to arc length. Even though the arc length is the variable of interest and the variable that should be controlled, the voltage is more easily monitored. Because of this, and the normal requirement that the arc voltage be specified in the welding procedure,

SECOND EDITION

MODERN WELDING TECHNOLOGY

HOWARD B. CARY

Senior Advisor, Welding Technology
Hobart Brothers Company

President, 1980-81
American Welding Society

Prentice Hall, Englewood Cliffs, New Jersey 07632

Library of Congress Cataloging-in-Publication Data

Cary, Howard B.
Modern welding technology / Howard B. Cary.—2nd ed.
p. cm.
Bibliography: p.
Includes index.
ISBN 0-13-599283-4
1. Electric welding. 2. Welding. I. Title.
TK4660.C37 1989
671.5'21—dc19 88-22697
CIP

EW-498-2nd Ed.

Editorial/production supervision
and interior design: Ed Jones
Cover design: Bruce Kenselaar
Manufacturing buyer: Robert Anderson
Page layout: Debbie Toymil
Cover photo: Comstock Inc./Jack Elness

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

ISBN 0-13-599283-4

Prentice-Hall International (UK) Limited, *London*
Prentice-Hall of Australia Pty. Limited, *Sydney*
Prentice-Hall Canada Inc., *Toronto*
Prentice-Hall Hispanoamericana, S.A., *Mexico*
Prentice-Hall of India Private Limited, *New Delhi*
Prentice-Hall of Japan, Inc., *Tokyo*
Simon & Schuster Asia Pte. Ltd., *Singapore*
Editora Prentice-Hall do Brasil, Ltda., *Rio de Janeiro*

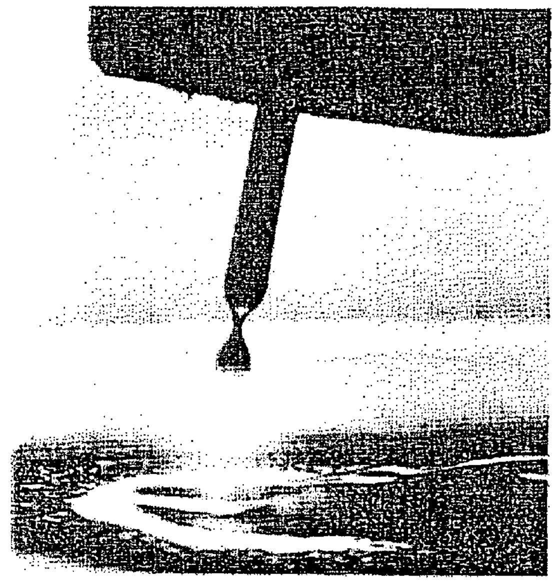
consumable electrode welding arc, also known as a "metallic arc," is a sustained high-current low-voltage electrical discharge through a highly conductive plasma that produces sufficient thermal energy which is useful for joining metals by fusion.

The consumable electrode welding arc (Figure 6-1) is a steady-state condition maintained at the gap between the tip of the melting electrode and the molten pool of the workpiece. The electrode is continuously fed into the arc and is melted by the heat of the arc. The molten metal of the electrode transfers across the arc gap to the workpiece, where it is deposited and upon solidification becomes the deposited weld metal. This is a very complex operation that is not completely understood.

The consumable electrode welding arc is a column of electrically and thermally excited gas atoms and ionized metal vapors from the electrode material known as a plasma. This plasma conducts current ranging from a few amperes to hundreds of amperes of either alternating current or direct current of either polarity. It has a voltage or potential drop of from 10 to 50 V. The plasma operates at a very high temperature, approximately 6000 °C (10,000 °F). A consumable electrode welding arc has a "point-to-plane" geometric configuration. Details of the arc region are shown in Figure 6-2.

In the metallic arc the high-temperature plasma causes the gas atoms in the arc to break down into positive ions and negative electrons. Electrons (negative) move from the cathode (negative) to the anode (positive). The ions (positive) move from the anode (positive) to the cathode (negative). In direct-current reverse-polarity (DCEP) gas metal arc welding, the common welding polarity, the electrons move from the workpiece to the electrode, and the positive ions move from the electrode

FIGURE 6-1 Consumable electrode welding arc.



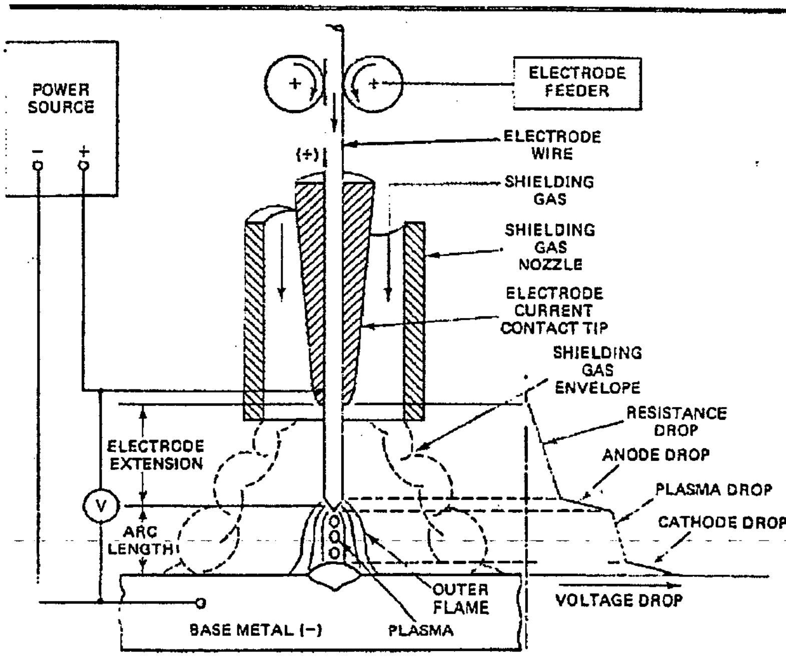


FIGURE 6-2 Arc region of the consumable electric arc.

to the workpiece. The largest portion of current flow is carried by the electrons. Conventional current flows from the electrode to the workpiece.

The potential gradiant along the axis of the arc is not uniform. The three voltage regions, known as the anode drop, the arc column or plasma drop, and the cathode drop, are also shown by the figure. The anode and cathode drops are extremely short in length but represent the largest gradient of the voltage potential. The total voltage potential in the arc is the sum of these three potential drop regions.[1] The theoretical arc heat energy available is governed by the welding current and the voltage drops of these three regions. Unfortunately, this is difficult to measure since a voltage meter, in a normal gas metal arc welding system, measures the voltage from the electrical current contact tip to the base metal workpiece. In the total arc region there is another potential drop known as the electrode resistance drop. This is the resistance to current flow through the electrode extension or stickout. This represents a fairly large drop based on the welding current, the diameter of the electrode, and the electrode composition. It is calculated as: electrode resistance drop $E = I^2 \times R$; I is the welding current and R is resistance of the electrode wire for the length of the extension. The heating of the electrode extension has a great effect on burn-off rates.

The relationship between welding current and arc voltage is not a straight line. The curve shown in Figure 6-3 is nonlinear and in the low-current area has a negative slope.[2] The major part of the curve shows that the arc voltage does increase with welding current, other conditions remaining the same. The welding current can be varied over a wide range of values from at least 20 A to over 500 A direct current.

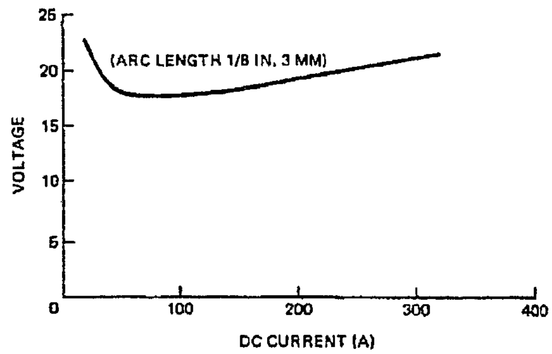


FIGURE 6-3 Arc voltage versus welding current of the metal arc in argon. (From Ref. 2.)

The length of the arc, or the arc gap, affects the arc voltage. A short arc which is approximately equal to one diameter of the electrode wire has the lowest voltage. The medium-length arc is in the medium-voltage range. The long arc is equal to about five times the diameter of the electrode and has the highest voltage. This is shown in Figure 6-4, which shows an aluminum arc in helium. The long arc becomes uncontrollable and it will not

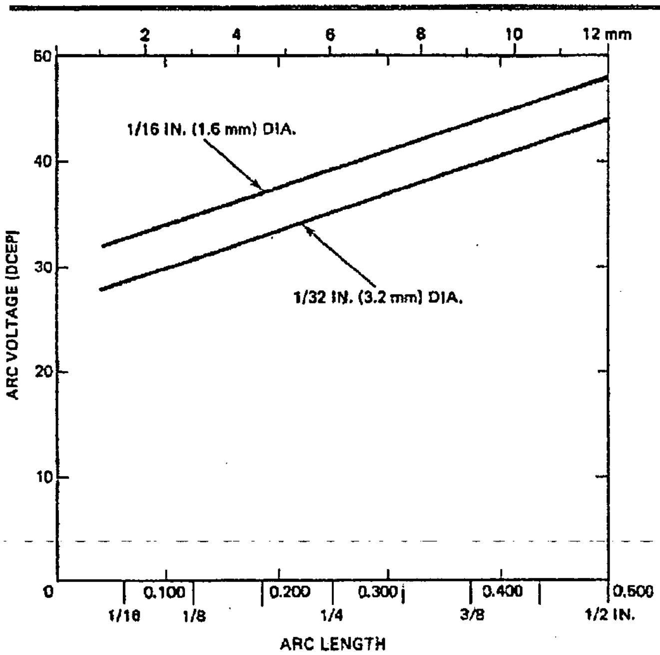


FIGURE 6-4 Arc length–arc voltage relationship. (From Ref. 3.)

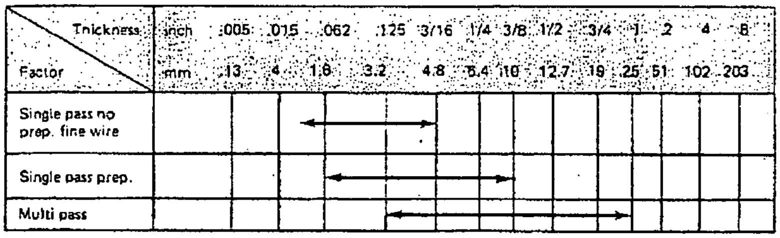


FIGURE 6-55 Base metal thickness range (GMAW).

the thinnest up to the thickest, by choosing the correct electrode wire type and size and gas for shielding.

Joint Design

The gas metal arc welding process can utilize the same joint design details that are used for the shielded metal arc welding process. These joint details are given in Chapter 19. For maximum economy and efficiency, weld joint details, specifically groove welds, should be modified. The overall diameter of the electrodes employed by gas metal arc welding are smaller than those employed for shielded metal arc welding. Because of this, the groove angles can be reduced (Figure 6-56). Reducing groove angles will still allow the electrode to be directed to the root of the weld joint so that complete penetration will occur.

The different variations require special attention concerning weld design. The CO_2 variation provides extremely deep penetrating qualities and in designing fillet welds, the size of the fillet can be reduced at least one size when converting from shielded metal arc welding to CO_2 welding.

The variation using inert gas on nonferrous metals can use the standard joint details recommended for shielded metal arc welding, except that the groove angle should be reduced. The joint designs used for pipe welding with shielded metal arc welding or gas welding are normally used for gas metal arc welding.

Welding Circuit and Current

The welding circuit employed for gas metal arc welding (Figure 6-57) uses a wire feeder system that controls the electrode wire feed and welding arc, as well as the flow of shielding gas and cooling water. The power supply is normally the constant-voltage (CV) type. A gun or torch is used for directing the electrode and shielding gas to the arc area. A travel system is required for mechanical welding.

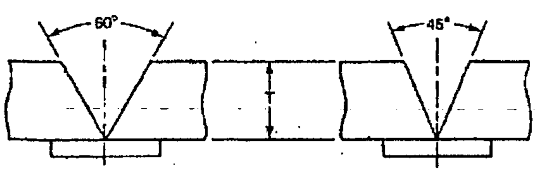
The gas metal arc welding process uses direct current. Alternating current has not been successfully used. Direct current is normally used with the electrode positive DCEP (reverse polarity). Direct-current electrode negative DCEN (straight polarity) can be used with special emissive-coated electrode wires, which provide for better electron emissions. DCEN is rarely used because the emissive-coated electrodes have a short storage life.

The shorting arc variation became popular when the constant-voltage system of welding power was introduced. The constant-voltage system reduced the complexity of the wire feed control circuits and eliminated electrode burnback to the contact tip or stubbing to the work. It also provided positive arc starting.

The pulsed-current variation requires a special power source which changes from a lower to a higher current at a frequency equal to or double that of the line frequency. This is normally 50 or 60 Hz and 100 or 120 Hz.

The welding current varies from as low as 20 A at a voltage of 18 V to as high as 750 A at an arc voltage of 50 V. This broad range of current and voltage encompasses all the variations.

FIGURE 6-56 Weld joint design difference (GMAW).



Equipment Required to Operate

The equipment required for a gas metal arc welding system (Figure 6-57) consists of (1) the power source, (2) the electrode wire feeder and control system, (3) the welding gun and cable assembly for semiautomatic welding or the welding torch for automatic welding, (4) the gas and water control system for the shielding gas and cooling water when used, and (5) travel mechanism and guidance for automatic welding.

Either a generator power source or a transformer-rectifier power source can be used; both are equally satisfactory. For the shorting arc variation the 200-A machine is normally used. CO_2 welding and spray arc welding require higher-current power sources up to 650

THE PROCEDURE HANDBOOK OF ARC WELDING

TWELFTH EDITION

This book may be ordered from any dealer or representative of The Lincoln Electric Company, or through any recognized book dealer in the world or direct from

THE LINCOLN ELECTRIC COMPANY
22801 St. Clair Avenue
Cleveland, Ohio 44117

LINCOLN ELECTRIC COMPANY OF CANADA, LTD.
179 WICKSTEED AVE., TORONTO 17, ONTARIO, CANADA

THE LINCOLN ELECTRIC CO. (Europe) S.A.
BOULEVARD de STALINGRAD, 76120 GRAND-QUEVILLY, FRANCE

LINCOLN ELECTRIC COMPANY (Australia)
35 BRYANT STREET, PADSTOW, N.S.W., 2211, AUSTRALIA

EXPORT REPRESENTATIVES

International Division Armco Steel Corporation
Post Office Box 700, Middletown, Ohio 45042, U.S.A.

the arc. The spray-arc technique is recommended for 1/8-in. and thicker sections, requiring heavy single or multipass welds or for any filler-pass application where high deposition rate is advantageous.

MIG welding is a DC weld process; AC current is seldom, if ever, used. Most MIG welding is done with reverse polarity (DCRP). Weld penetration is deeper with reverse polarity than it is with straight polarity. MIG welding is seldom done with straight polarity, because of arc-instability and spatter problems that make straight polarity undesirable for most applications.

The gas metal-arc process can be used for spot welding to replace either riveting, electrical resistance, or TIG spot welding. It has proved applicable for spot welding where TIG spot welding is not suitable, such as in the joining of aluminum and rimmed steel. Fitup and cleanliness requirements are not as exacting as with TIG spot welding, and the MIG process may be applied to thicker materials.

The MIG process is also adaptable to vertical electrogas welding in a manner similar to that used with the gas-shielded flux-cored electrode process (see Section 6.5).

GAS TUNGSTEN-ARC WELDING

The AWS definition of gas tungsten-arc (TIG) welding is "an arc welding process wherein coalescence is produced by heating with an arc between a tungsten electrode and the work." A filler metal

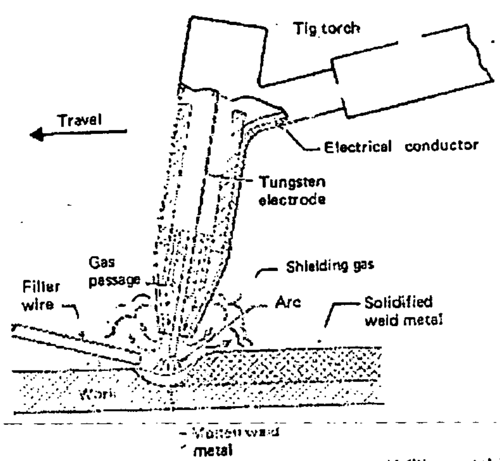


Fig. 5-15. Principles of the gas tungsten-arc process. If filler metal is required, it is fed into the pool from a separate filler rod.

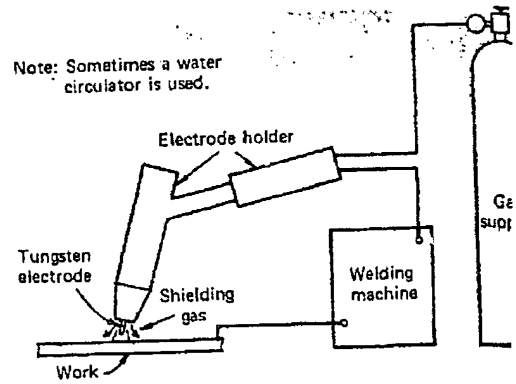


Fig. 5-16. Schematic of manual TIG welding.

may or may not be used. Shielding is obtained a gas or a gas mixture.

Essentially, the nonconsumable tungsten trode is a "torch" — a heating device. Unde protective gas shield, metals to be joined m heated above their melting points so that ma from one part coalesces with material fror other part. Upon solidification of the molten unification occurs. Pressure may be used whe edges to be joined are approaching the molter to assist coalescence. Welding in this m requires no filler metal.

If the work is too heavy for the mere fus abutting edges, and if groove joints or rein ments, such as fillets, are required, filler meta be added. This is supplied by a filler rod, manu mechanically fed into the weld puddle. Both of the nonconsumable tungsten electrode a tip of the filler rod are kept under the protect shield as welding progresses.

Figure 5-15 illustrates the TIG torch, an 5-16 a schematic for manual TIG welding. The of manually feeding filler rod into the weld is illustrated in Fig. 5-17. In automatic w filler wire is fed mechanically through a gui the weld puddle. When running heavy joints ally, a variation in the mode of feeding is to press the filler rod in or along the joint and along with the joint edges. All of the standar of joints can be welded with the TIG proc filler metal.

Usually the arc is started by a high-fre high-voltage device that causes a spark to jun the electrode to the work and initiate the current. Once the arc is started, the elec moved in small circles to develop a pool of

[redacted]

Maximum overlap is attainable if the backhand technique is used on the second side.

For the best quality welds, some bevel should be provided. A 60° single or double-V joint is recommended. A root opening of zero to 1/16-in. should be maintained. Double-V welds can tolerate wider openings than single-V welds. In single-V grooves, a sealing pass from the reverse side will generally be required unless the fitup is uniform.

Plates 1/4-in. thick and thicker generally require single or double-V grooves with 60° included angles. It is generally advantageous to employ a double V. Less metal is needed to fill the joint and less distortion results when welding from alternate sides.

For both types of joints, zero root face is recommen [redacted] he root passes. A root [redacted] d unless an opening larger than normal can be maintained to insure penetration. Uniform penetration is obtainable in joints having no root face if the opening is held less than 3/32-in.

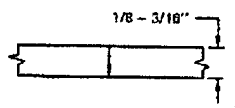
Poor fitup and root overlap should be avoided. Where variations in spacing greater than 1/16 in. are encountered, copper backup strips will prevent excessive penetration.

U grooves should be employed on plate thicker than 1 in. They require considerably less weld metal. Root spacings should be maintained between 1/32 and 3/32 in. Root face should be kept below 3/32 in. to assure adequate penetration.

PROCEDURES FOR GAS METAL-ARC WELDING CARBON-STEEL BUTTS BY SPRAY TRANSFER

Gas — Argon with 5% O_2

Gas Flow 40-50 cfh



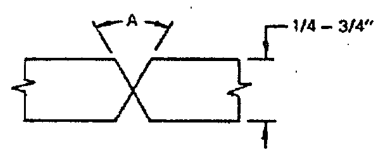


Plate Thickness (in.)	1/8	3/16	1/4		5/16		1/2		3/4
Electrode Size	1/16	1/16	3/32		3/32		3/32		3/32
Pass	1	2	1	2	1	2	1	2	1 – 4
Current DCRP	280	375	375	430	400	420	400	450	450
Wire Speed (ipm)	165	260	83	95	87	92	87	100	100
Voltage	24	26	27		28		28		29
Arc Speed (ipm)	20	24	24		20		14		12
Total Time (hr/ft of weld)	0.0100	0.0167	0.0167		0.0200		0.0286		0.0667
Angle A (degrees)	·		60		60		60		90

Welding Handbook

Seventh Edition, Volume 2

Welding Processes– Arc and Gas Welding and Cutting, Brazing, and Soldering

W.H. Kearns, Editor

AMERICAN WELDING SOCIETY
2501 Northwest 7th Street
Miami, Florida 33125

Library of Congress Number: 75-28707
International Standard Book Number: 0-87171-148-6

American Welding Society, 2501 N.W. 7th Street, Miami, FL 33125

Printed in the United States of America

4
Gas Metal Arc Welding

FUNDAMENTALS OF THE PROCESS

DEFINITION AND GENERAL DESCRIPTION

Gas metal arc welding (GMAW) is an electric arc welding process which produces coalescence of metals by heating them with an arc established between a continuous filler metal (consumable) electrode and the work. Shielding of the arc and molten weld pool is obtained entirely from an externally supplied gas or gas mixture, as shown in Fig. 4.1. The process is sometimes referred to as MIG or CO_2 welding.

When GMAW was first developed, it was considered to be fundamentally a high current density, small diameter, bare metal electrode process using an inert gas for arc shielding. Its primary application was for welding aluminum. As a result, the term MIG (Metal Inert Gas) was used and is still the most common reference for the process. Subsequent developments include operation at low current densities and pulsed direct current, application to a broader range of materials, and the use of reactive gases (particularly CO_2) or gas mixtures. This latter development has led to the formal acceptance of the term gas metal arc welding (GMAW) for the process because both inert and reactive gases are used.

GMAW is operated in semiautomatic, machine, and automatic modes. It is utilized particularly in high production welding operations. All commercially important metals such as carbon steel, stainless steel, aluminum, and copper can be welded with this process in positions by choosing the appropriate shieldi gas, electrode, and welding conditions.

ARC POWER AND POLARITY

The vast majority of GMAW applicatic require the use of direct current reverse polar (electrode positive). This type of electrical cc nection yields a stable arc, smooth metal transf relatively low spatter loss, and good weld be characteristics for the entire range of weldi currents used. DCE

Direct current straight polarity (electro negative) is seldom used, since the arc c become very unstable and erratic even though t electrode melting rate is higher than th achieved with dcrp (electrode positive). Wh employed, dcsp (electrode negative) is used conjunction with a "buried" arc or short circu ing metal transfer. Penetration is lower wi straight polarity than with reverse polarity dire current.

Alternating current has found no comme cial acceptance with the GMAW process for tv reasons: (1) The arc is extinguished during ea half cycle as the current reduces to zero, and may not reignite if the cathode cools sufficientl and (2) Rectification of the reverse polarity cyc promotes the erratic arc operation. A mo detailed discussion on the effect of polarity c metal transfer can be found in Chapter *Welding Handbook*, Volume 1, 7th editio

METAL TRANSFER

Filler metal can be transferred from the electrode to the work in two ways: (1) when the electrode contacts the molten weld pool thereby establishing a short circuit, which is known as short circuiting transfer (short circuiting arc welding); and (2) when discrete drops are moved across the arc gap under the influence of gravity or electromagnetic forces. Drop transfer can be either globular or spray type.

Shape, size, direction of drops (axial or nonaxial), and type of transfer are determined by a number of factors. The factors having the most influence are

(1) Magnitude and type of welding current
(2) Current density
(3) Electrode composition
(4) Electrode extension
(5) Shielding gas
(6) Power supply characteristics

Axially directed transfer refers to the movement of drops along a line that is a continuation of the longitudinal axis of the electrode. Nonaxially directed transfer refers to movement in any other direction.

Short Circuiting Transfer

Short circuiting arc welding uses the lowest range of welding currents and electrode diameters associated with GMAW. Typical current ranges for steel electrodes are shown in Table 4.1. This type of transfer produces a small, fast freezing weld pool that is generally suited for the joining of thin sections, for out-of-position welding, and for the filling of large root openings. When weld heat input is extremely low, plate distortion is small. Metal is transferred from the electrode to the work only during a period when the electrode is in contact with the weld pool. There is no metal transfer across the arc gap.

The electrode contacts the molten weld pool at a steady rate in a range of 20 to over 200 times each second. The sequence of events in the transfer of metal and the corresponding current and voltage are shown in Fig. 4.2. As the wire touches the weld metal, the current increases. It would continue to increase if an arc did not form, as shown at E in Fig. 4.2. The rate of current increase must be high enough to maintain a molten electrode tip until filler metal is transferred. Yet, it should not occur so fast that it causes spatter by disintegration of the transferring drop of filler metal. The rate of current increase is controlled by adjustment of the inductance in the power source. The value of inductance required depends on both the electrical resistance of the welding circuit and the temperature range of electrode melting. The open circuit voltage of the power source must be low enough so that an arc cannot continue under the existing welding conditions. A portion of the energy for arc maintenance is provided by the inductive storage of energy during the period of short circuiting.

As metal transfer only occurs during short circuiting, shielding gas has very little effect on this type of transfer. Spatter can occur. It is usually caused by either gas evolution or electromagnetic forces on the molten tip of the electrode.

Globular Transfer

With a positive electrode (dcrp), globular transfer takes place when the current density is relatively low, regardless of the type of shielding gas. However, carbon dioxide (CO_2) shielding yields this type of transfer at all usable welding currents. Globular transfer is characterized by a drop size of greater diameter than that of the electrode.

Globular, axially directed transfer can be achieved in a substantially inert gas shield without spatter. The arc length must be long enough to assure detachment of the drop before it contacts the molten metal. However, the resulting weld is likely to be unacceptable because of lack of fusion, insufficient penetration, and excessive reinforcement.

Carbon dioxide shielding always yields nonaxially directed globular transfer. The departure from axial motion is due to an electromagnetic repulsive force acting upon the bottom of the molten drop, as shown in Fig. 4.3. Flow of electric current through the electrode generates several forces that act on the molten tip. The most important of these are pinch force *(P)* and anode reaction force *(R)*. The magnitude of the pinch force is a direct function of welding current and wire diameter, and is usually responsible for

drop detachment. With CO_2 shielding, the wire electrode is melted by the arc heat conducted through the molten drop. The electrode tip is not enveloped by the arc plasma. The molten drop grows until it detaches by short circuiting or gravity, as *R* is never overcome by *P*. High speed photography shows that the arc moves over the area between the molten drop and workpiece, while *R* tends to support the drop. Spatter can therefore be very severe.

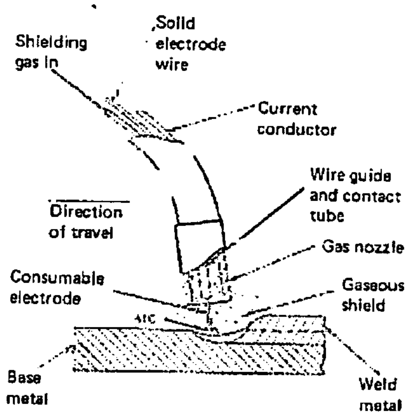


Fig. 4.1—Gas metal arc welding process

Spray Transfer

In a gas shield of at least 80 percent argon or helium, filler metal transfer changes from globular to spray type as welding current increases for a given size electrode. For all metals, the change takes place at a current value called the globular-to-spray transition current. Table 4.2 lists transition currents for various metal electrodes.

Spray type transfer has a typical fine arc column and pointed wire tip associated with it. Molten filler metal transfers across the arc as fine droplets. The droplet diameter is equal to or less than the electrode diameter. The metal spray is axially directed. The reduction in droplet size is also accompanied by an increase in the rate of droplet detachment, as illustrated in Fig. 4.4. Metal transfer rate may range from less than 100 to several hundred droplets per second as the electrode feed rate increases from approximately 42 to 340 mm/s (100 to 800 in./min).

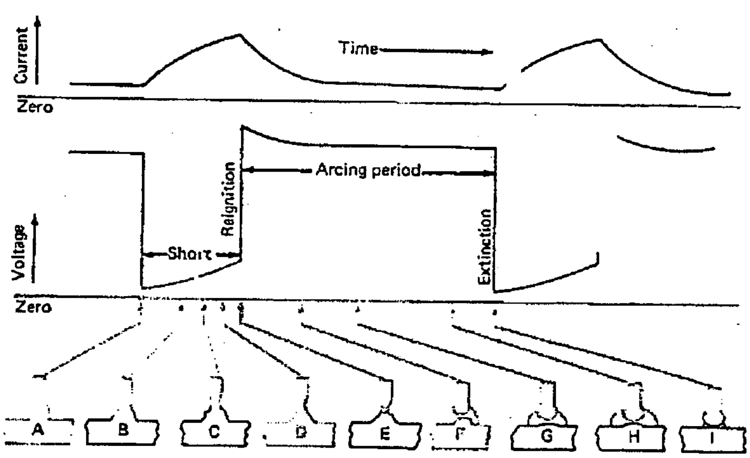


Fig. 4.2—Oscillograms and sketches of short circuiting arc metal transfer

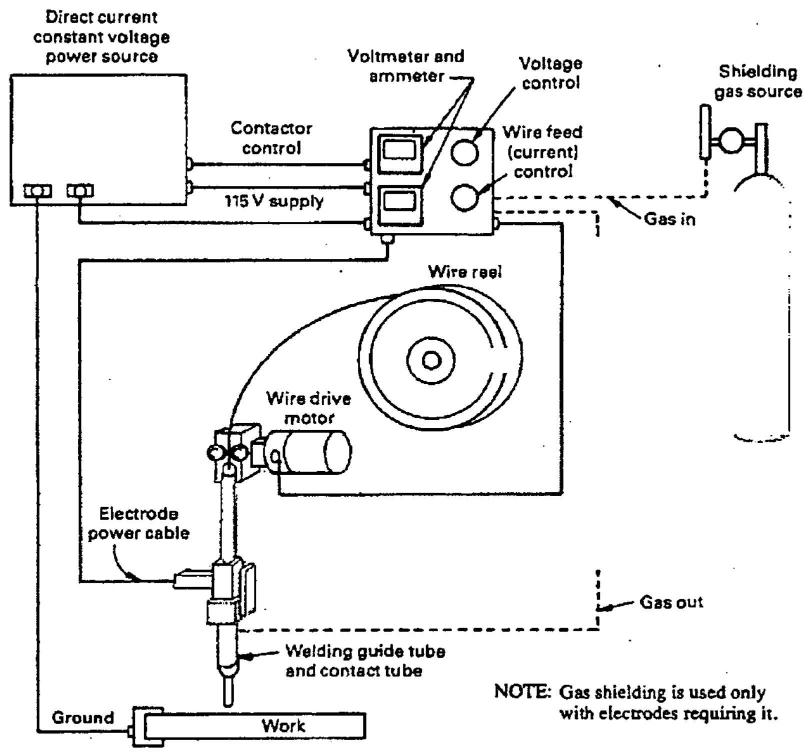


Fig. 5.7—Typical flux cored automatic arc welding equipment

which the electrode is designed. Here the "0" means that the electrode is designed for flat and horizontal positions. However, small sizes of the classification may be suitable for vertical or overhead positions, or both.

The letter "T" indicates that the electrode is of tubular construction (a flux cored electrode). The suffix number (in this example "1") places the electrode in a particular grouping built around the chemical composition of deposited weld metal, method of shielding, and suitability of the electrode for single or multiple pass welds.

Mild steel FCAW electrodes are classified on the basis of whether or not carbon dioxide is required as a separate shielding gas, the type of current, their usability for welding position and number of weld passes, and the chemical composition and as-welded mechanical properties of deposited weld metal. Electrodes are designed to produce weld metals having specified chemical compositions and mechanical properties when the welding and testing are done to the specification requirements.

Electrodes are produced in standard sizes ranging from 1.58 to 3.97 mm (1/16 to 5/32 in.)

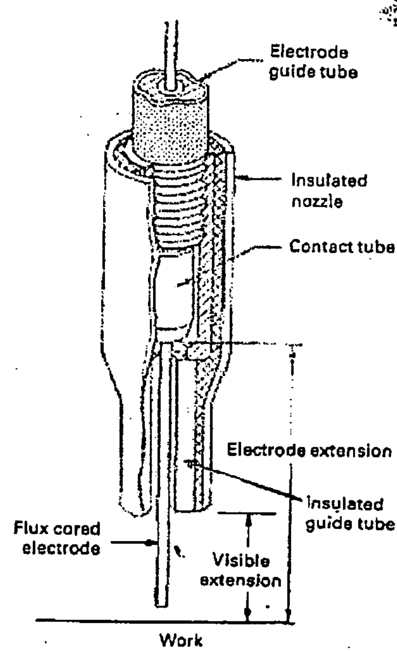


Fig. 5.6—Self-shielded electrode nozzle

of the ingredients in the core (in combination with the composition of the sheath), it is possible to

(1) Produce welding characteristics ranging from high deposition rates in the flat position to proper fusion and bead shape in the overhead position

(2) Produce electrodes for various gas shielding mixtures and for self shielding

(3) Vary alloy content of the weld metal from mild steel for certain electrodes to high alloy stainless steel for others

The primary functions of the flux core ingredients are to

(1) Provide the mechanical, metallurgical, and corrosion resistant properties of the weld metal by adjusting the chemical composition

(2) Promote weld metal soundness by shielding the molten metal from oxygen and nitrogen in the air

(3) Scavenge impurities from the molten metal by use of fluxing reactions

(4) Produce a slag cover to protect the solidifying weld metal from the air, and to control the shape and appearance of the bead in the different welding positions for which the electrode is suited

(5) Stabilize the arc by providing a smooth electrical path to reduce spatter and facilitate the deposition of uniformly smooth, properly sized beads

Table 5.1 lists most of the elements commonly found in the flux core, their sources, and the purposes for which they are used.

In mild and low alloy steel electrodes, a proper balance of deoxidizers and, in the case of self-shielded electrodes, denitrifiers must be maintained to provide a sound weld deposit with adequate ductility and toughness. Deoxidizers, such as silicon and manganese, combine with oxygen to form stable oxides. This helps to control the formation of carbon monoxide which causes porosity, and also the loss of alloying elements through oxidation. The denitrifiers, such as aluminum, combine with nitrogen and tie it up as stable nitrides. This prevents nitrogen porosity and the formation of other nitrides which might be harmful.

CLASSIFICATIONS OF ELECTRODES

Mild Steel Electrodes

Most mild steel FCAW electrodes are classified according to the requirements of AWS A5.20, Specification for Mild Steel Electrodes for Flux Cored Arc Welding. The classification system follows the general pattern for electrode classification. It may be explained by considering a typical designation, E70T-1.

The prefix "E" indicates an electrode, as in other electrode classification systems. The first number refers to the minimum as-welded tensile strength, in 10 ksi units. In this example, the number "7" indicates that the electrode has a minimum tensile strength of 70 ksi. The second number indicates the welding positions for